Silicon Detectors - Outline

- **Part I**
  - Physics Requirements
  - Solid State Detector Physics
    - Field maximum at junction side
    - Carrier mobilities define current signal
  - Detector Design
    - Radiation hard structures
    - Care in internal fields, oxide layers to avoid breakdown
  - Radiation Damage
    - Increase in Vdep/Type inversion
    - Increase in $I_{leakage}$
- **Part II**
  - Electronics and readout
  - Mechanical and construction
  - Production and Testing
- **References**

  - Radeka, Ann. Rev. Nucl. Part. Sci. 1988, 217-277.
  - Helmudt Spieler lecture notes (www-physics.lbl.gov/~spieler)
  - Sze, Physics of Semiconductor Devices
  - CMS and ATLAS notes

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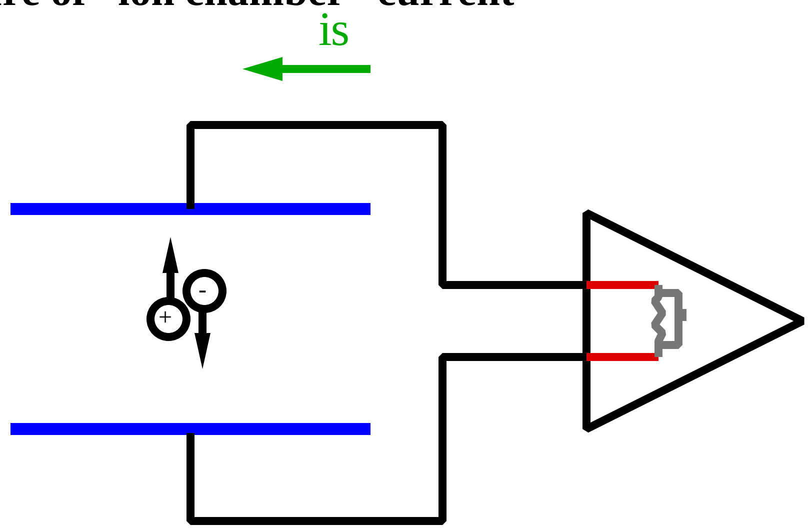
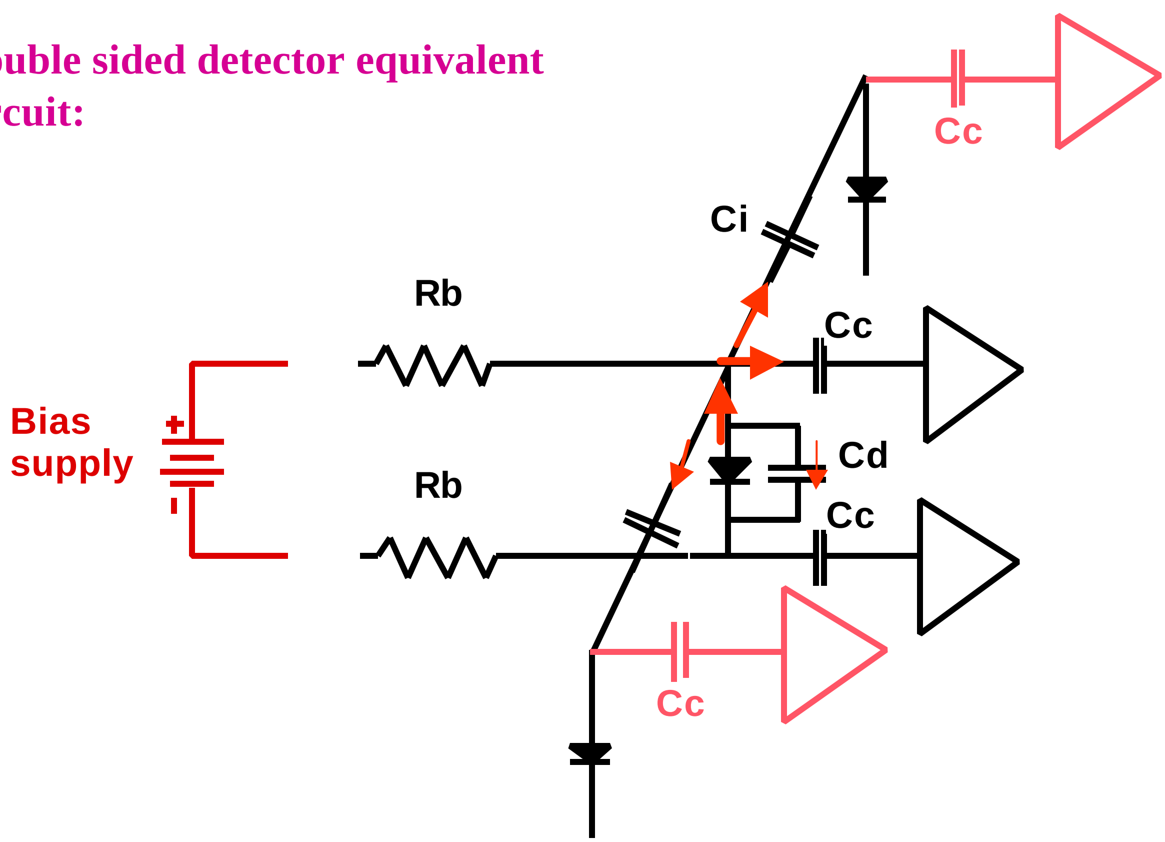
Electronics and Readout - Equivalent Circuit

Simple picture of "ion chamber" current



Moving charge in the gap induces a current in the circuit

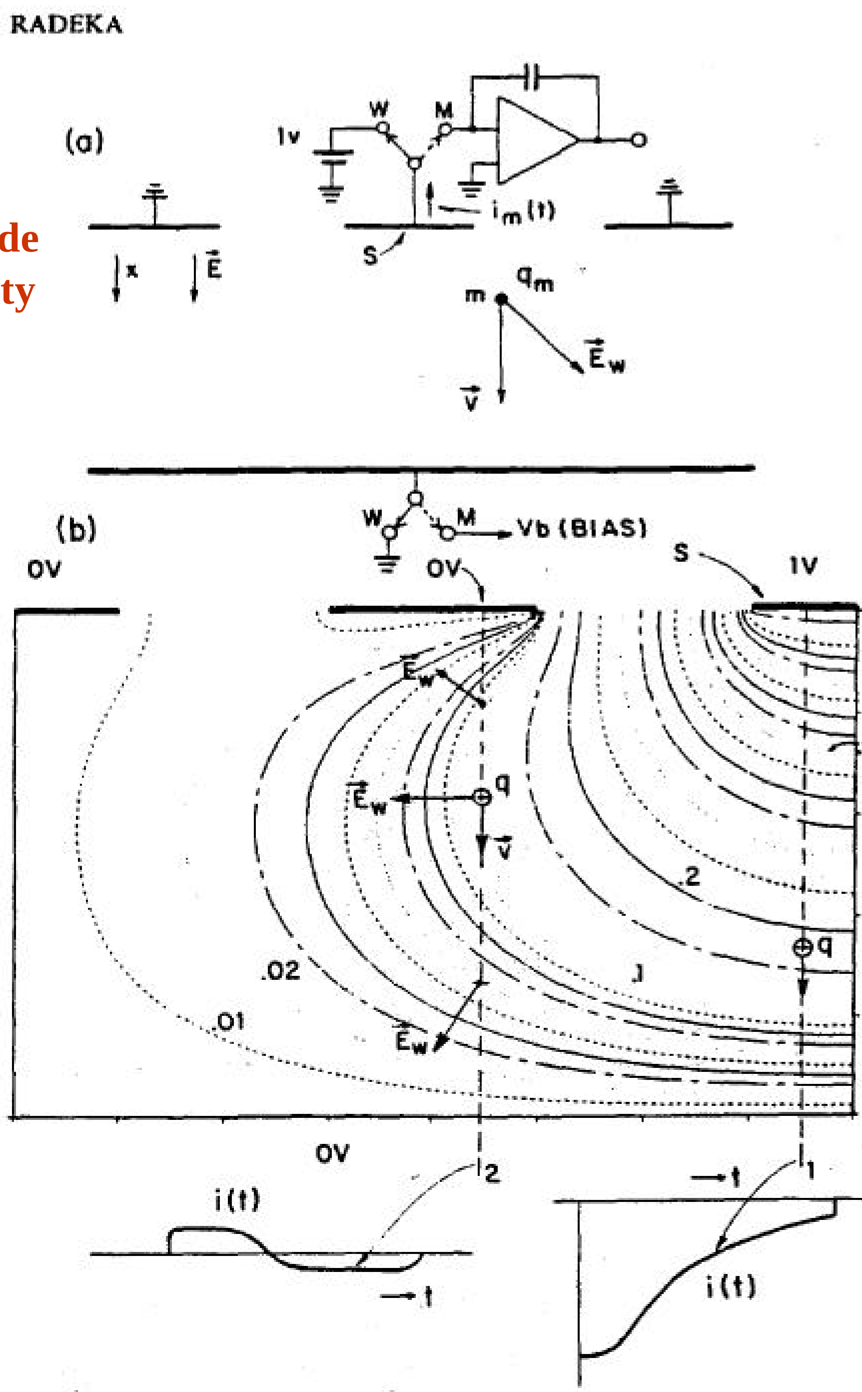
Double sided detector equivalent circuit:



Electronics and readout - signal development

Signal induced by moving charges depend on *work* done by circuit. The charge induced on an electrode depends on the coupling between the moving charge and the electrode.

In a multi-electrode system the induced current on an electrode depends on the velocity of the charge and the value of the effective "weighting" field



Weighting field - determined by putting 1V on strip, grounding all other electrodes

$$i = q\vec{E}_w \bullet m\vec{E}$$

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Electronics and readout - Capacitance

Capacitances:

C_{ac} = coupling capacitance

~10pf/cm dependent on thickness and composition of dielectric.

Thin oxide - larger coupling capacitance, large signal, lower Vb, more fragile structure

C_b = backplane capacitance

~0.1 pf/cm - due to parallel plate front-back coupling, dependent on depletion

C_i = interstrip capacitance

~ 1 pf/cm - usually dominant preamplifier load. Dependent on detector layout, surface and oxide charges, irradiation. Is larger for n-side due to p-stop coupling. Also larger for double metal devices

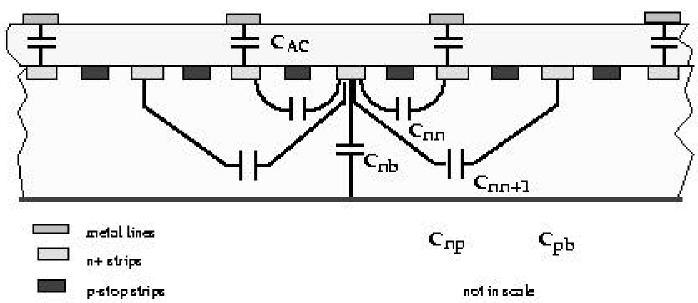
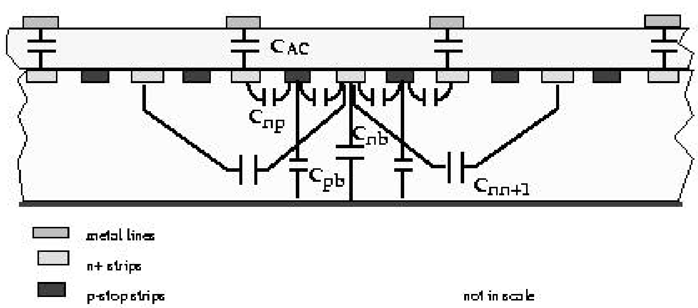


Figure 8,a



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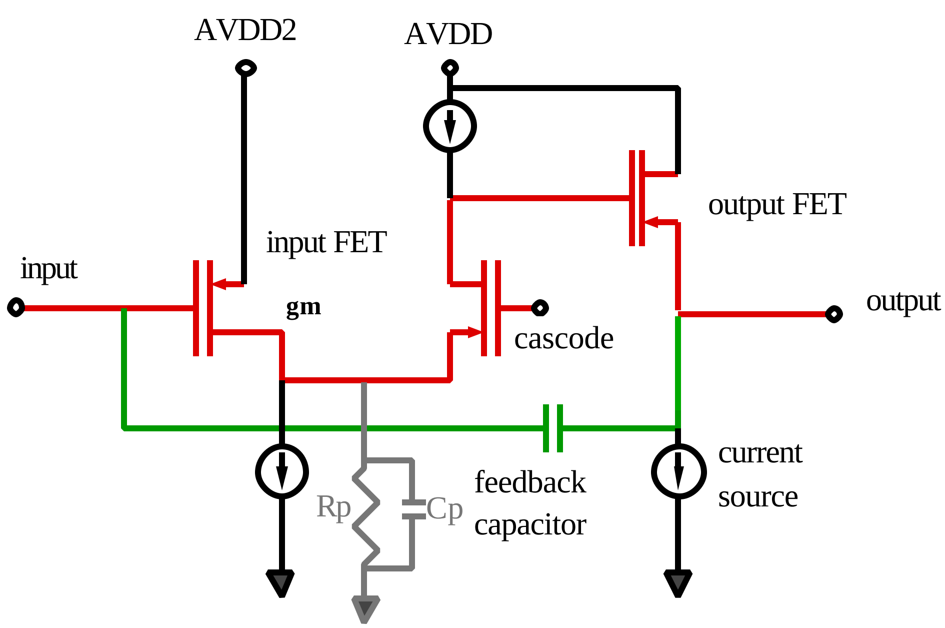
Electronics and readout - The CMOS preamp

- **Breakthrough (microplex chip) low noise compact preamplifiers can be fabricated using standard CMOS processes**
  - **Small amplifier pitches (40 microns)**
  - **Low noise**
  - **Radiation hard processes available**



Basic equations:

$$t = R_p C_p$$

$$g_m = \frac{\P I_d}{\P V_g}$$ **transductance**

$$A_o = g_m R_p$$ **open loop gain**

$$gain = 1/C_f$$ **volts/coulomb**

$$t_{in} = t / A_o C_f$$

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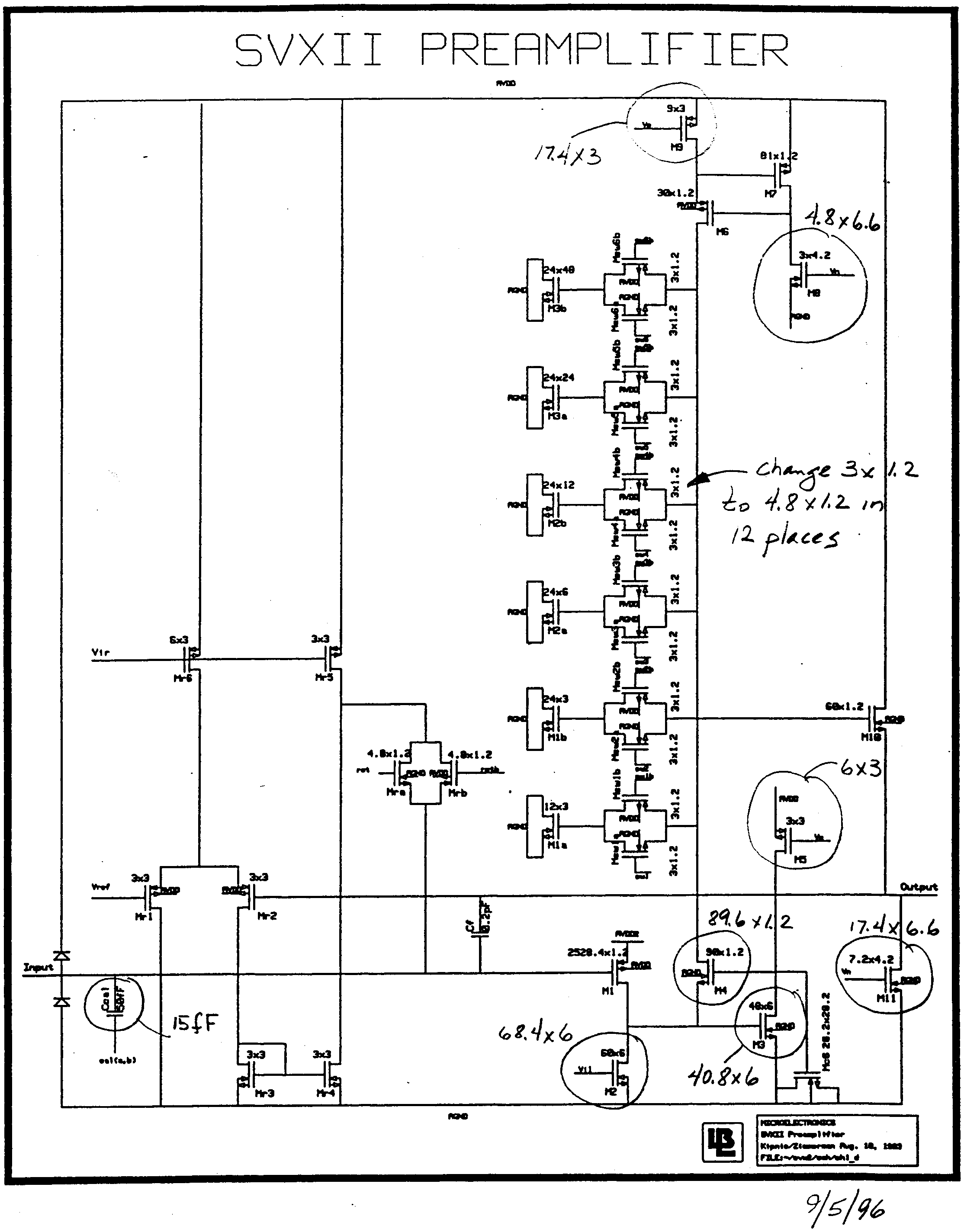
SVX II Front End



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Signal/Noise

Noise sources:

- **Preamp noise - due to charge fluctuations in input transistor. Proportional to load capacitance:**

$$ENC = a + bC_{load}$$

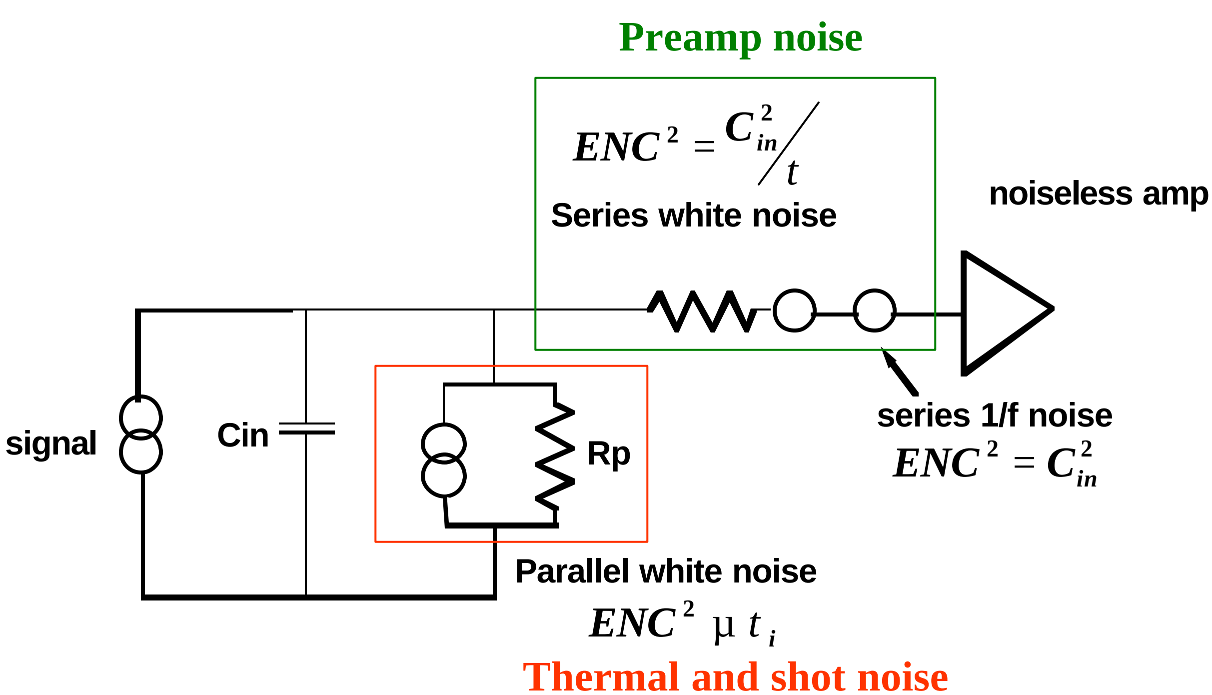
- **Shot noise in trip leakage current**

$$ENC = q_e\sqrt{N_e}$$

- **Thermal noise in bias resistor**

$$ENC = \sqrt{kTt/2R_b}$$

- **Thermal noise of series resistors**



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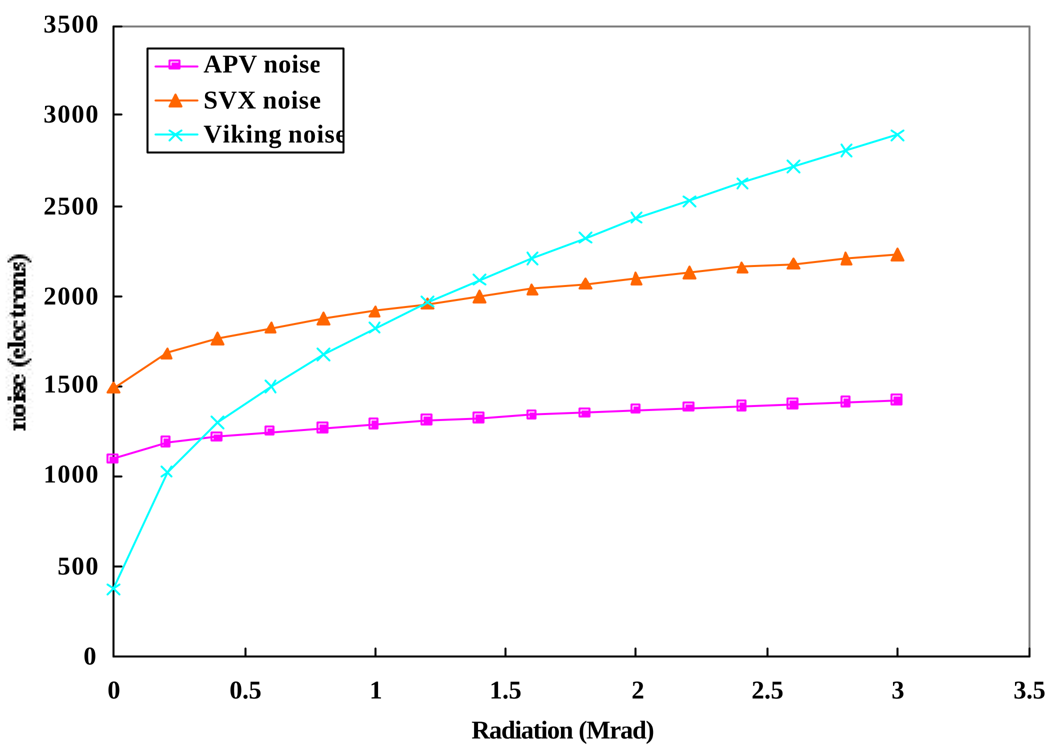
Signal/Noise

- **Amplifiers can be optimized for noise performance in specific applications:**

Silicon Readout chips

Chip	t	noise	Power	Application
Viking	1.5 ms	135e +12 e/pf	1.5 mW/ch	long strips, slow response,e+e-
SVX II/III	132 ns	490e+50 e/pf	5 mW/ch	Fermilab collider
APV	25 ns	500e+30 e/pf		LHC (CMS)

Silicon Readout Chips



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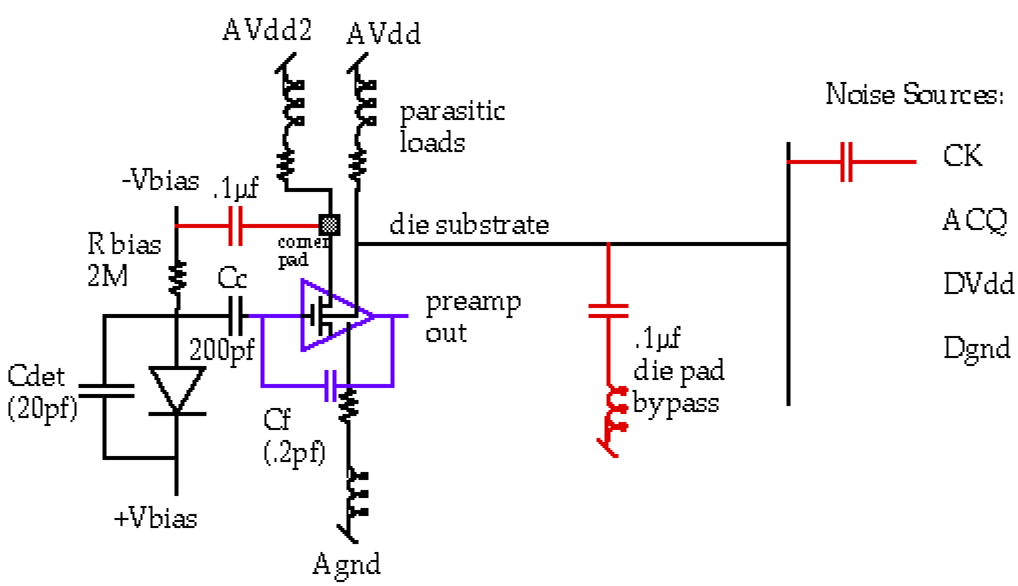
Electronics and Readout

Real problems in a detector are often dominated by system design

- **Power distribution and cabling**
- **Noise coupling from**
  - **other detectors**
  - **outside world (SCRs …)**
  - **digital to analog sections of the chip**
- **Ground loops and uncontrolled current paths**

- **98% of the work is on “Real World” problems**

SVX 2 Front end equivalent circuit showing noise sources and suggested bypass



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Pixel Detectors

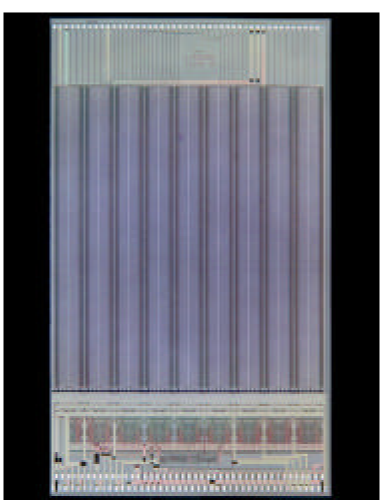
Two dimensional array of readout electrodes on a silicon detector

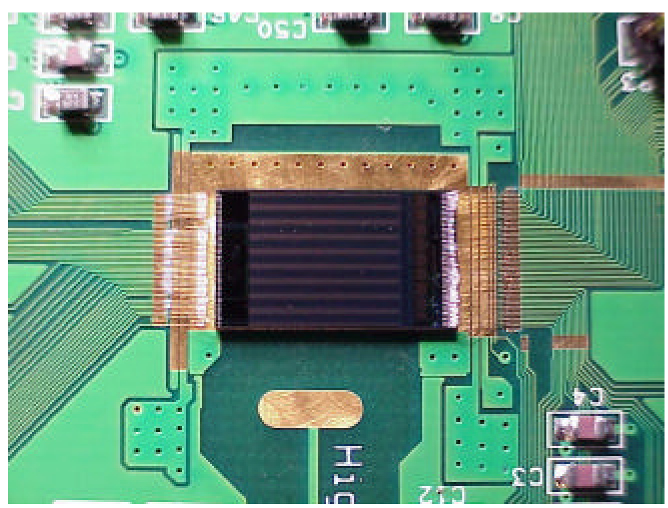
- **Two dimensional readout**
  - **Typically rectangular (50x400 mm)**
- **Very low input capacitance S/N~150/1**
- **“Radiation hard” due to large S/N margin**

Sounds great but…

- **Connection to readout requires more complex “bump bonding” - “sandwich” of detector and readout using Indium or solder bumps**
- **Readout must be organized to efficiently identify and readout hit pixels. Challenging design.**
- **Amplifiers are distributed … more complex cooling/services**

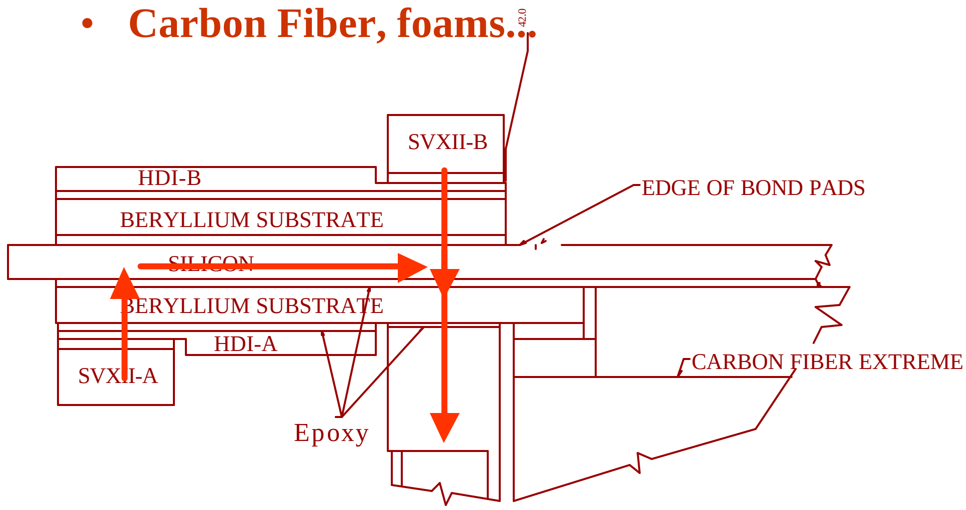
BTEV FPIX1

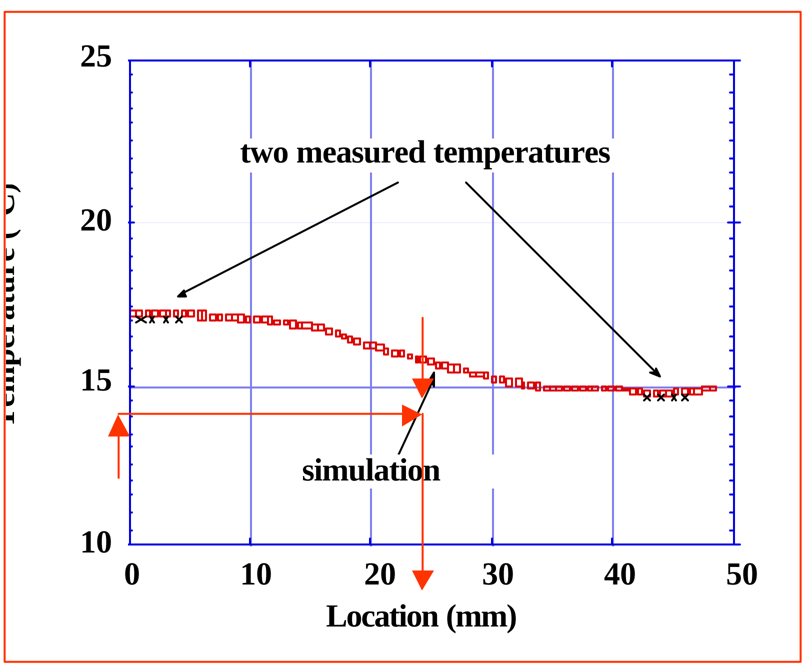




Mechanical and construction - Cooling

- **Need to keep detectors at low temperature to control reverse annealing and leakage currents**
  - **Remove head from readout chips**
  - **High thermal conductivity, low mass materials**
    - **Be, BeO**
    - **Graphite (pyrolitic)**
    - **Carbon Fiber, foams...**





Cooling channel

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Thermal Runaway

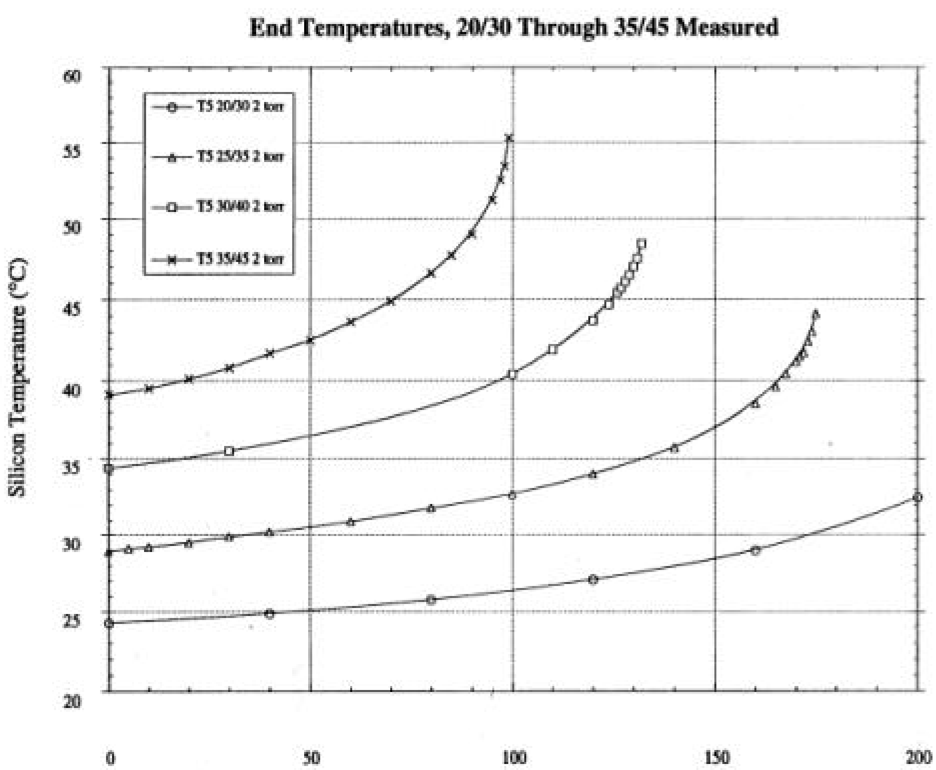
Irradiated detectors leakage currents increase as:

$$\Delta I_{leak} = \alpha \phi V$$

Depletion voltages also increase with the result that the power generated by the detector itself Vbias x Ileak becomes significant. This power can cause a temperature rise which, in turn will increase the current:

$$I_{leak} = T^2 e^{-\frac{1.2eV}{2kT}}$$

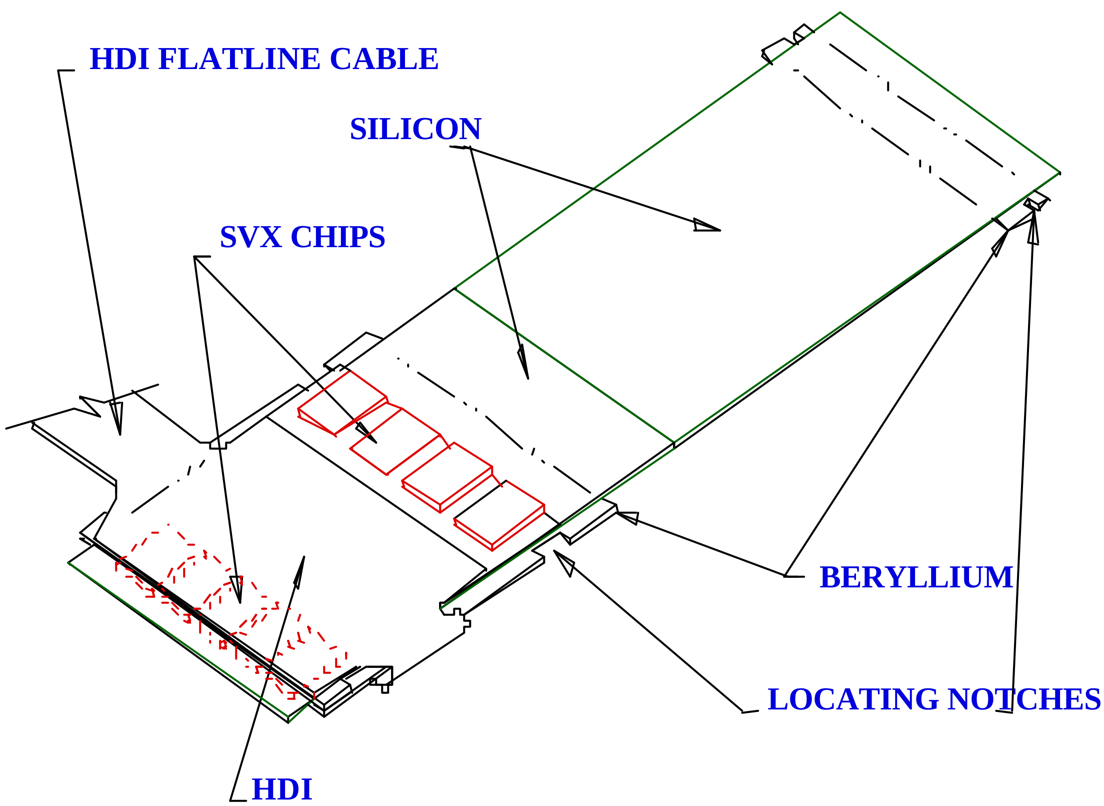
causing "thermal runaway" and an unusable detector if the heat cannot be removed.



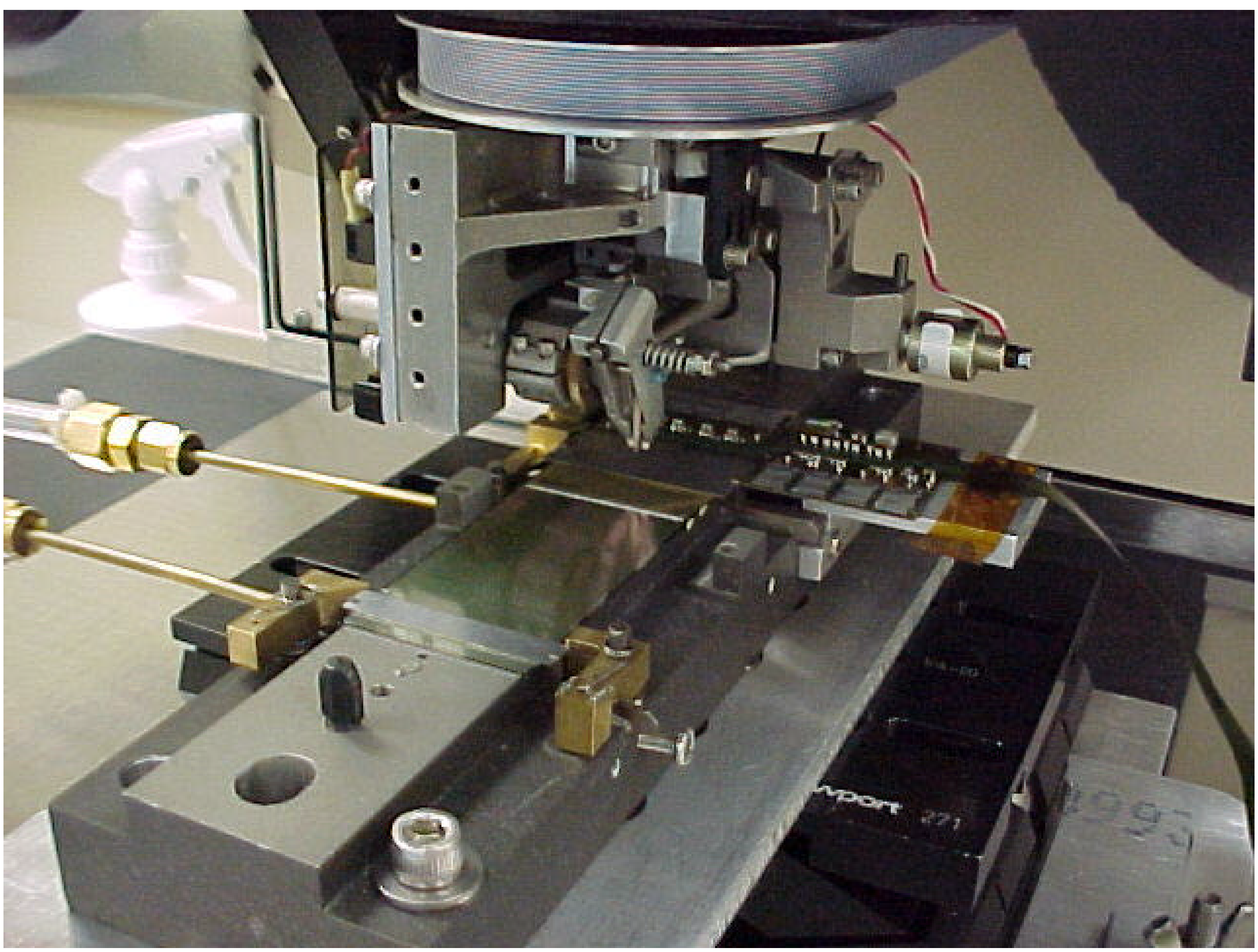
KEK/CDF study

Mechanical and construction - Support

- Mechanical Support
  - alignment of assembly wrt support structure
    - 2-20 μm depending on trigger requirements
    - maintainance of alignment + fiducials
  - support of silicon crystals
    - detectors can bow ~100 μm
  - cooling of readout electronics
    - water/water-glycol/silicon oil/cleaning fluid
  - access for wirebonding/interconnects




UMM 500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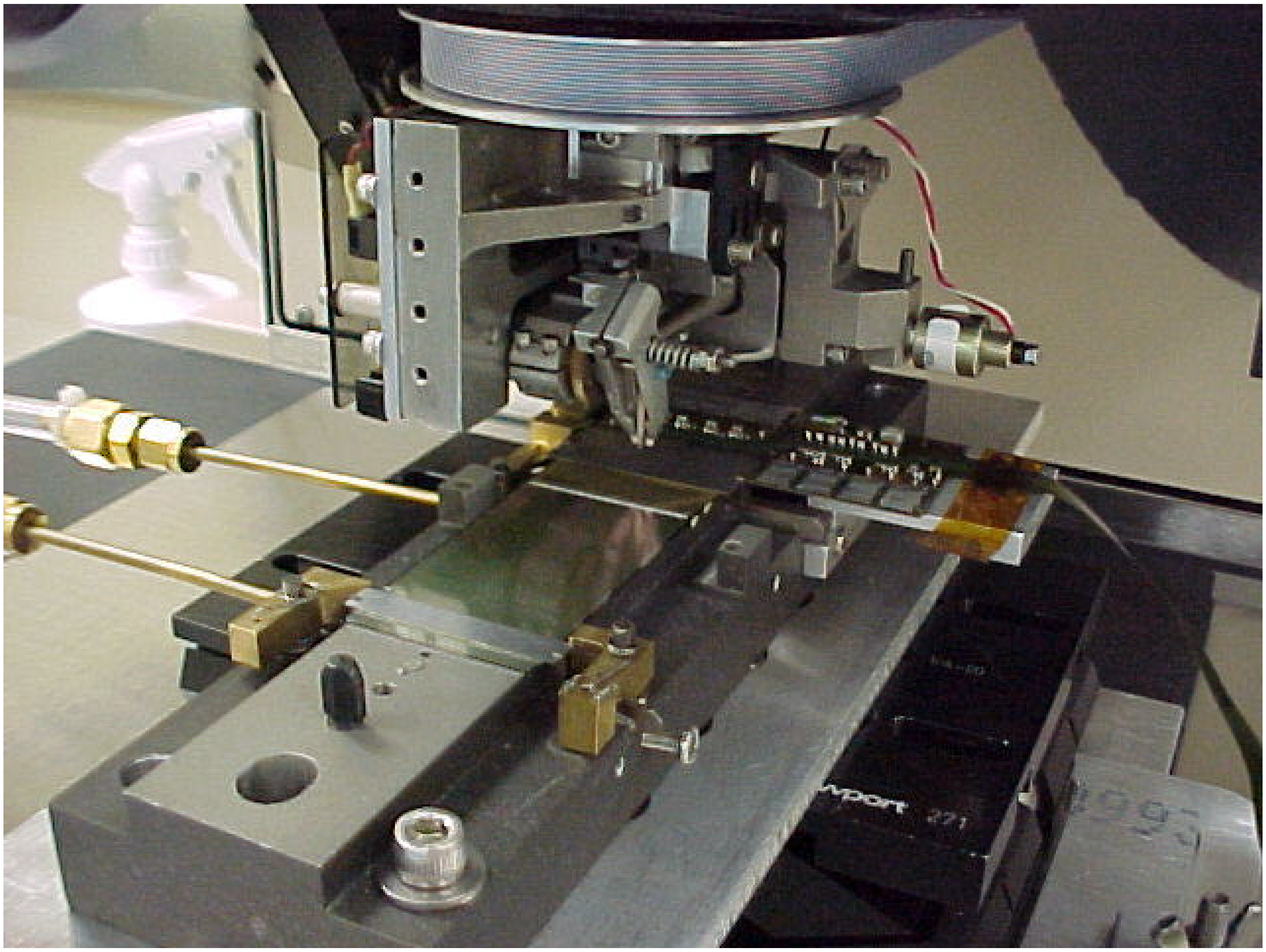
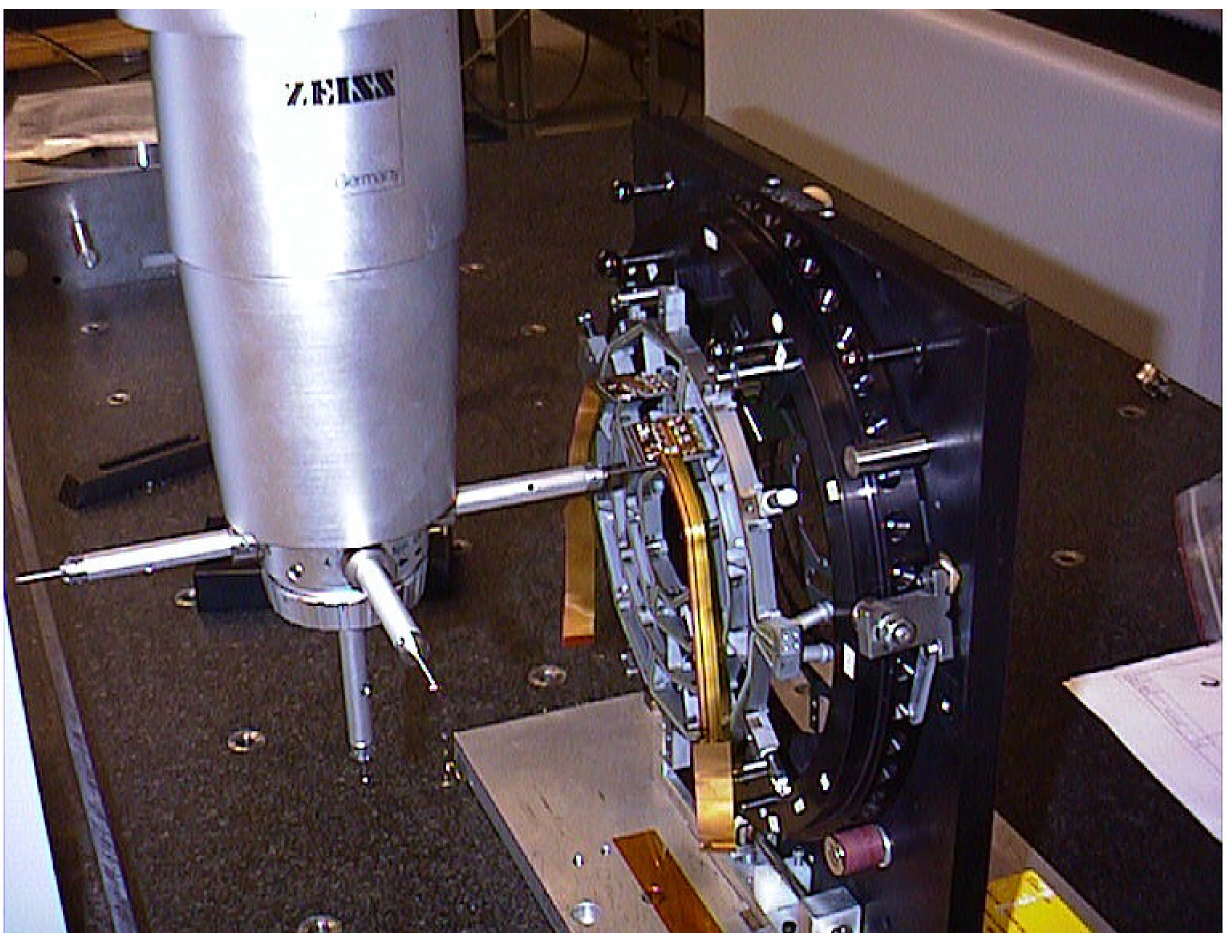
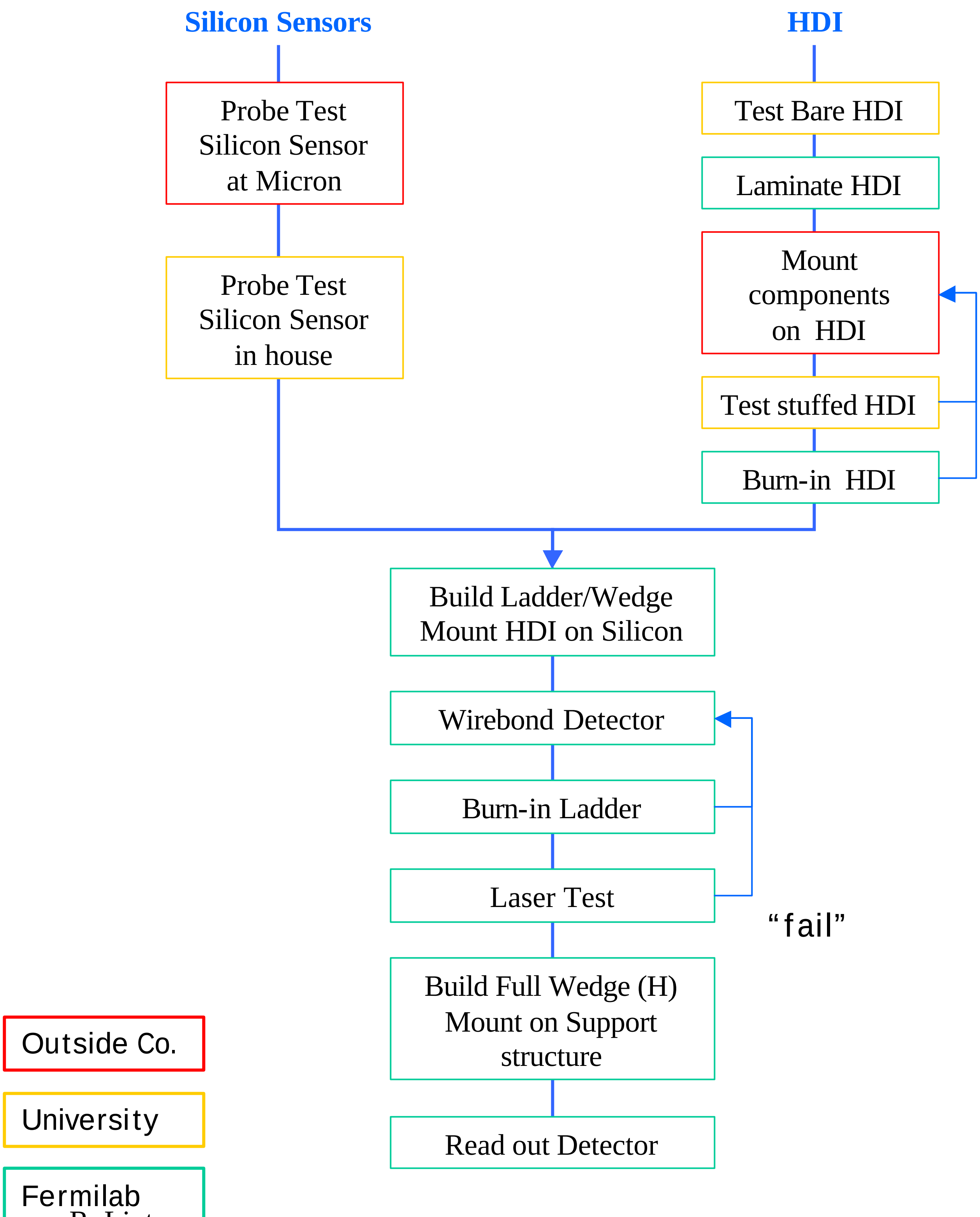
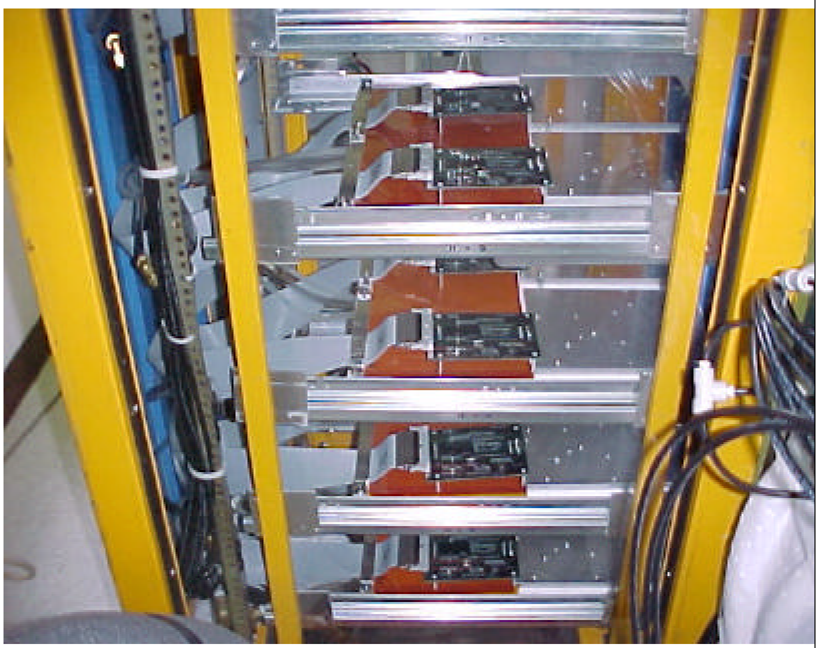


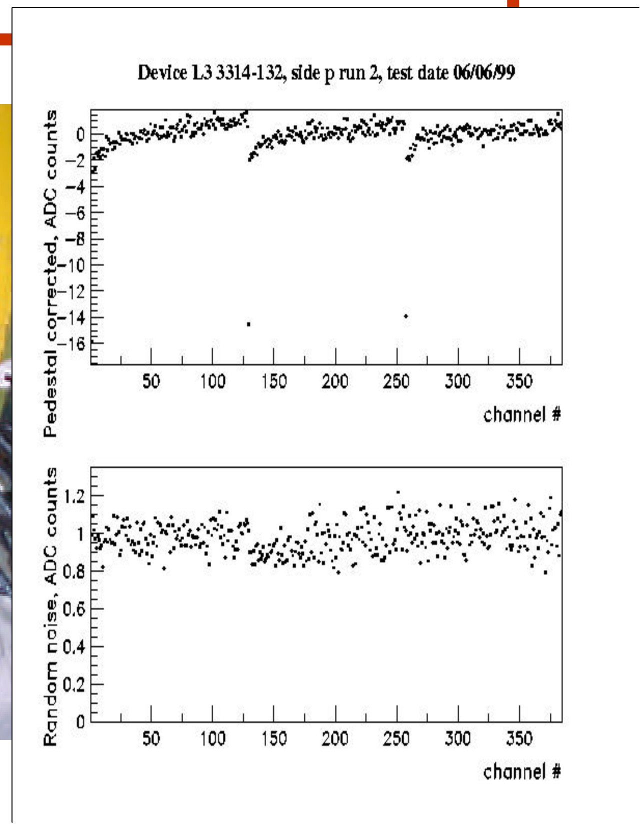

ZEISS

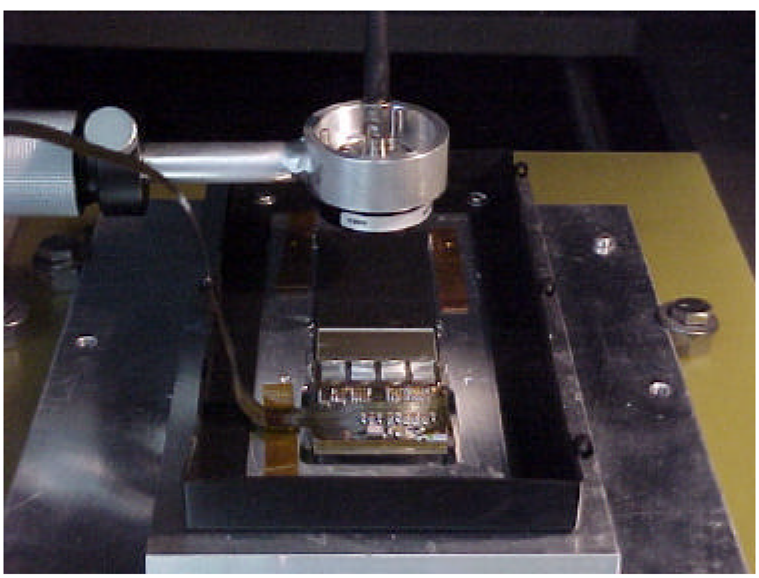
Production and Testing

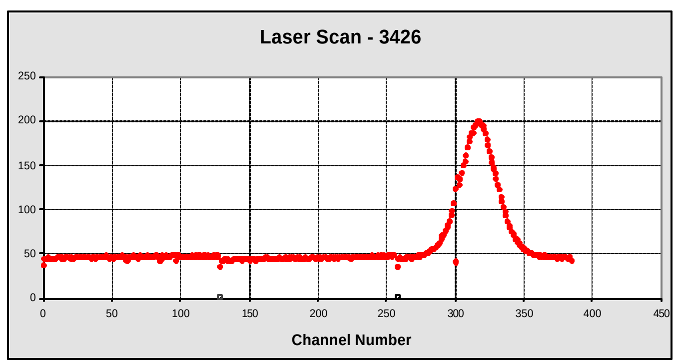


Production Testing









(Demarteau)

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Conclusions

• Silicon detectors are complex devices with substantial requirements for understanding the underying physics

- **Fields**
- **Charge transport**
- **Radiation damage**
- **Thermal properties**
- **Microelectronics**

It's very easy to get burned

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